

Latest News from Double Chooz Reactor Neutrino Experiment

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Abstract. Double Chooz experiment will search for a disappearance of the reactor neutrinos from Chooz reactor cores in Ardenne, France, in order to detect the yet unknown neutrino oscillation angle θ_{13} . The far detector was completed in 2010 and data-taking has started in spring 2011. Status of data-taking is presented and some performance plots from physics data are shown in this paper for the first time. Also the prospect of experimental sensitivity is presented, in light of recent indication from T2K for a non-zero θ_{13} value.

Keywords: neutrino, neutrino oscillation, reactor, mixing angle, liquid scintillator

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INTRODUCTION

Unlike the quark sector, the nature of lepton mixing phenomenon is still poorly revealed. Especially, while two other angles are large, the mixing angle θ_{13} seems to be small and only an upper limit $\sin^2 2\theta_{13} < 0.15$ has been set [1]. Measurement of this angle is one of the most important tasks of neutrino physics in next few years, as the value of θ_{13} determines the detectability of CP violation phase δ_{CP} in future experiments.

Oscillation probability for mixing angle θ and mass difference $\Delta m^2 (\text{eV}^2)$ is $\sin^2 2\theta \sin^2 (1.27 \Delta m^2 L / E)$, where L is distance (km) and E is neutrino energy (GeV). For $\Delta m_{31}^2 = 2.5 \times 10^{-3} \text{eV}^2$, this corresponds to first oscillation maximum at a few 100 km for accelerator neutrino ($E \approx 1 \text{ GeV}$), while it is 1~2 km for reactor neutrino of $E \approx 4 \text{ MeV}$. (For the same energy, KamLAND explores the sector $\Delta m_{21}^2 = 8 \times 10^{-5} \text{eV}^2$ at much larger distances.)

Therefore, the principle of reactor θ_{13} experiment is to measure the electron anti-neutrino flux precisely at a distance of 1~2 km from the source and detect disappearance (the energy is not enough for appearance of other leptons). Since it is a pure θ_{13} measurement, it is complementary to accelerator appearance experiment and both methods are necessary to yield richer physics results. To reduce the uncertainties related to source flux estimation, new-generation reactor experiments (Daya Bay in China, Double Chooz in France and RENO in Korea) have a concept of placing identical detectors at near (before oscillation) and far locations and make a ratio of the two measurements.

All these experiments have a liquid scintillator (LS) target doped with Gd, using the Inverse- β reaction $\bar{\nu}_e p \rightarrow e^+ n$. Gd has a very large neutron absorption cross section. The positron deposits its kinetic energy and annihilates in the target, giving rise to a prompt signal. The neutrino energy can be measured from this signal. The neutron drifts in the target and thermalizes, finally absorbed by Gd which emits a few γ rays with a total energy of 8 MeV. This signal occurs $\sim 30 \mu\text{s}$ after the prompt signal on average and is called the delayed signal. Making "delayed coincidence" of these two signals is a key to separate a neutrino signal from the large backgrounds from environment and cosmic rays.

DOUBLE CHOOZ EXPERIMENT

The details of the experiment are described elsewhere [2]. The detector has four layers of cylindrical vessels: the neutrino target (Gd-doped LS), Gamma-catcher (LS without Gd) which detects γ rays from neutrino interaction that escaped from the target, Buffer layer (non-scintillating mineral oil) to shield the active region from external γ rays mainly from photomultiplier (PMT) glass, and Inner Veto (LS) to veto cosmic rays. Inner Detector (up to Buffer layer) and Inner Veto are optically separated and viewed by 390 and 78 PMTs, respectively.

In Dec. 2010, filling of liquids in the far detector was finished and the main far detector was completed. From Jan. 2011, commissioning of the detector (such as HV tuning) was done and physics data-taking started from Apr. 2011. In parallel, installation of Outer Veto (plastic scintillator strips to track cosmic muons) is on-going and its lower part has already been completed. Glove Box for calibration (to deploy radioactive and other sources) has just been installed.

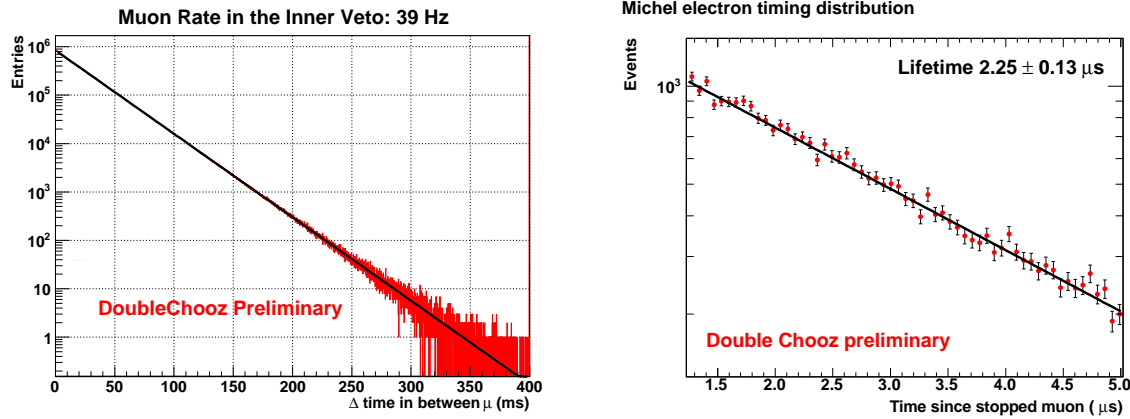


FIGURE 1. (left) Distribution of time between two muon events in Inner Veto. (right) Michel electron timing distribution.

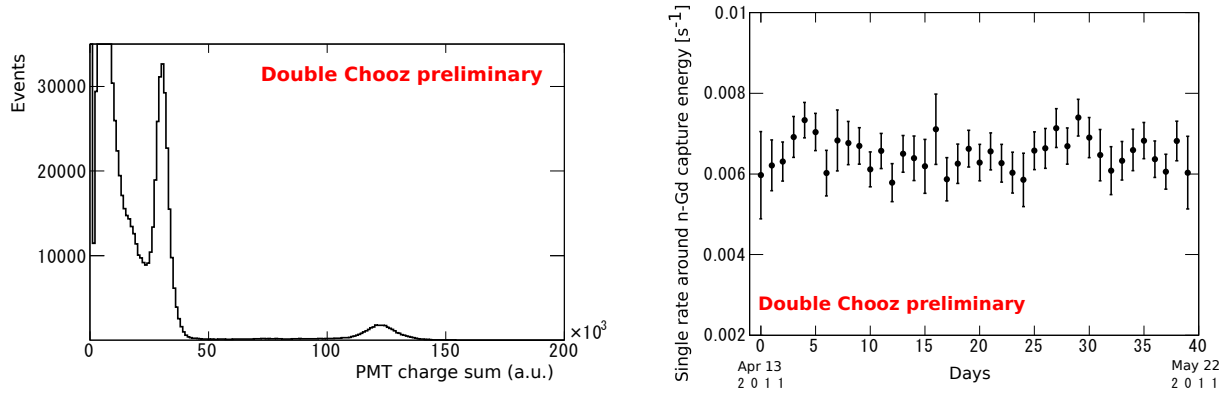


FIGURE 2. (left) Delayed energy in muon-correlated time window. (right) Singles rate in delayed energy window vs. date.

For the near detector, civil construction of the tunnel and the lab hall is ongoing, and will be finished in Apr. 2012. The detector construction will then follow, expected to be finished by the end of 2012. After that, the data-taking will be in "double" mode with reduced systematic uncertainties.

Stable data-taking for physics started on 13 Apr. with on-site shifters and remote shifts in three time-zones. Data acquisition efficiency is more than 85% of the time. It includes calibration runs with light injection by embedded fibers. Trigger rate is about 120 Hz. So far, already 70 days of physics data have been accumulated. Still detailed checks on data are to be made, but preliminary plots from physics runs are shown in the next section.

DATA FROM PHYSICS RUNS

Figure 1(left) shows the time distribution between muon events tagged by Inner Veto. About 40 Hz of muons are detected, while about 10 Hz of muons are detected in Inner Detector. Figure 1(right) shows the Michel electron timing distribution from stopped muons. The life time is consistent with muon decay, demonstrating that delayed coincidence technique is working well.

Figure 2(left) shows the delayed energy distribution in muon-correlated time window. Note that it is from raw data, without gain calibration nor energy calibration/correction. Clean peaks are seen for neutron capture by H (2.2 MeV) and Gd (8 MeV). Events in H capture includes interactions in γ -catcher volume. Figure 2(right) shows the stability of singles rate in delayed energy window (currently 6 to 12 MeV), after vetoing muon-correlated events. The rate is well below 0.01 Hz, which is less than half of the proposal value (0.024 Hz, which was scaled from Chooz experiment).

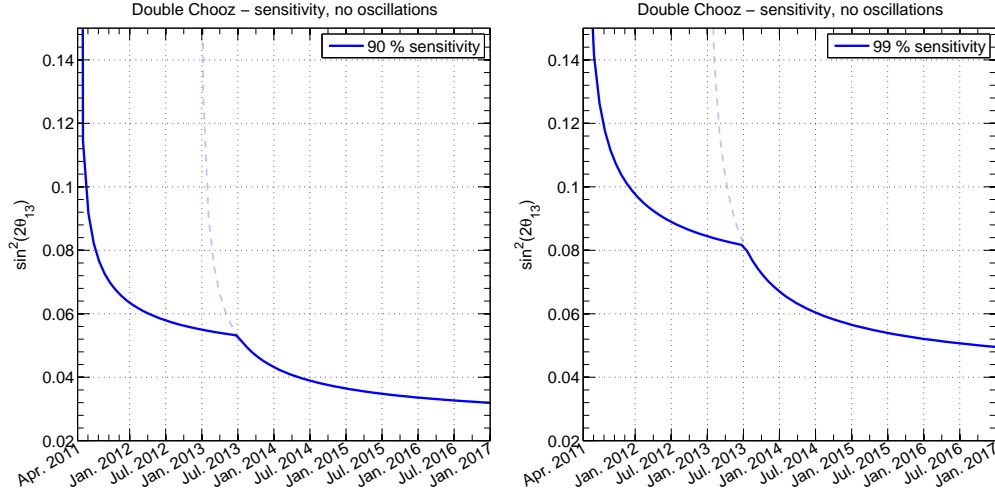


FIGURE 3. Sensitivity on $\sin^2 2\theta_{13}$ as a function of time at (left) 90% and (right) 99% Confidence Level.

The singles rate in prompt energy window (currently 0.7 to 12 MeV) is 10 Hz, as was expected in the proposal and much lower than previous Chooz experiment (64.8 Hz) thanks to the new Buffer layer.

From these observed performances, the accidental coincidence rate is expected to be small enough and a clean set of neutrino candidates is anticipated in the current data. Detailed studies on correlated backgrounds (fast neutrons and long-lived isotopes induced by cosmic rays) will also be made.

PROSPECTS

Figure 3 shows the revised sensitivity of Double Chooz as a function of time, in which the start of near-detector data-taking is set to end of 2012. Physics data-taking efficiency of 80% and reactor duty-cycle of 80% are assumed. Both rate and spectral shape information of neutrino events are used in oscillation analysis. For the far-detector only phase, normalization error of 2.5% and bin-to-bin uncorrelated error of 2% are assumed.

Recently T2K collaboration observed an indication of electron appearance from muon neutrino beam [3]. Their result converts to confidence interval of $0.03(0.04) < \sin^2 2\theta_{13} < 0.28(0.34)$ at 90% C.L. for normal (inverted) hierarchy. The best-fit point is $\sin^2 2\theta_{13} = 0.11(0.14)$. It can be seen that T2K's best-fit values can be addressed at 99% C.L. with Double Chooz 2011 data, and almost all 90% C.L. interval can be covered by Double Chooz at 90% C.L. in full data set.

SUMMARY

Double Chooz experiment started to take physics data. The challenging "four-layer vessel" detector concept, developed by Double Chooz colleagues around 2002, has proved to work after the construction period of 2008 - 2010. Still detailed checks and calibrations are to be made, but the performance from raw data already looks promising towards observing a nice neutrino signal. Given a hint from T2K for non-zero θ_{13} , the interplay between reactor and accelerator measurements will bring exciting time in neutrino physics.

REFERENCES

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